A brief introduction and investigation of doubly magic Nickel

Yuefeng Li

04/26/2018

Abstract

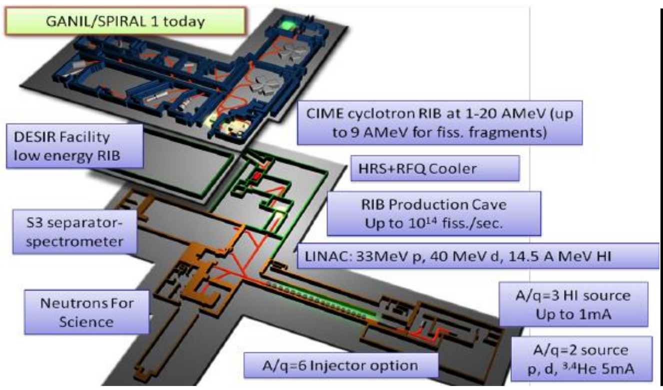
Background: For each atom, if the electrons fill up the energy level or called “shell”, the energy which is required to kick one electron out from the atom would be largest. In other word, the atom is relatively stable. Moreover, in the atom nucleus, the nucleons (proton and neutron) can also be arranged in the shells. Each time a shell has the maximum number of nucleons it can accommodate. The atom nucleus becomes particularly stable. These maximum number of nucleons are called “magic number”. They are 2, 8, 20, 28, 50, 82 and 126. The atom nucleus contains two types of nucleon. If both of proton and neutron of one atom completely fill up the shell with magic number, it called doubly magic. **Purpose:** Understand what doubly magic is. To know the ways to investigate, observe and even create the doubly magic in laboratory currently. **Method:** A collaboration of physicists enforced the process to investigate the doubly magic ^{48}Ni at GANIL. They emit a primary beam of ^{58}Ni to hit the natural Nickel target, to reproduce the doubly magic ^{48}Ni nucleus. Two teams tried to observe the doubly magic ^{78}Ni nucleus. One team used the knockout reaction, the other team performed the advanced measurement to weigh the mass of copper isotopes, and then used the ion traps to weigh each nuclei to obtain their binding energy. **Result:** The doubly magic ^{48}Ni is the most recent discovered doubly magic element, the experiment of observing the doubly magic Nickel is at GANIL. Two research team which led by Oliver and Welker used two different approaches to search the ^{79}Cu isotope, which is just one proton away from the doubly magic ^{78}Ni. **Conclusion:** Theoretically, when one element contains the magic number of proton, some of their corresponding isotopes can become doubly magic element only if it has magic number of neutron as well. Specifically, the Nickel consists 28 protons, which is a magic number. Therefore, it can become doubly magic Nickel if it has the magic number of neutron as well.

Introduction

The universe is made up by various atoms. Each kind of atom have their particular number of electron, proton and neutron. The atomic nucleus is collection of protons and neutrons. Electrons move around the nucleus with high speed. Basically, the numbers of proton and neutron are equal in most atoms. The proton carries one positive electrical charge; the neutron is changeless. Then, in nucleus, the protons affect the repulsive force by coulomb potential from other protons. The protons would be still bounded in the nucleus. This binding energy which bound the nucleons inside the nucleus called nuclear strong force. Through lots of experiments and observations by physicists. They found if the number of proton of one atom is 2, 8, 20, 28, 50, 82 and126. The binding energy of the nucleus is relatively maximum. Which mean it requires more energy to kick one nucleon out from the atom. These number are called "magic number". Just like the electrons can fill their shell to become more stable. The protons and neutrons also can possess extra stability once they fill completely in the shells in nucleus. The magic number are the requirement of shells. The "magic numbers" was firstly pointed by Maria Goeppert-Mayer in 1949. She stated that the protons and neutrons would be more stable if the number of them are 2, 8, 20, 28, 50, 82 and 126. She was awarded by Nobel Prize for Physics dut to her discovery in 1963. And the discovery of magic numbers developed the nuclear shell model [5]. Moreover, if both number of proton and neutron satisfy the magic number in one particular atom, it can be called "doubly magic". This paper mainly talks about the doubly magic Nickel; which the number of proton is 28. It can become doubly magic Nickel if the number of neutron is magic number as well.

Discovery of doubly magic ^{48}Ni

Nowadays, there are about 2500 different known nuclear isotopes. However, there are few known doubly magic atoms. Only 10 doubly magic atoms were discovered. The most recent is ^{48}Ni [2]. The ^{48}Ni contains 28 protons and 20 neutrons. In the drip lines, ^{48}Ni is beyond the proton drip line. Then the ^{48}Ni is unstable with respect to the strong interaction. And the ^{48}Ni can have alpha decay due to its position which is beyond the proton drip line. Specifically, the decay model of ^{48}Ni is emitting two protons to form a helium nucleus. In addition, ^{48}Ni is the only doubly magic nucleus with the bound mirror nucleus, which leads to the mirror symmetry studies. The first directly detection of doubly magic ^{48}Ni happened in September 1999. The collaboration of French, Polish and Romanian physicists enforced the experiment to search the doubly magic ^{48}Ni at the GANIL in Caen, France. (Figure 1) To search the doubly magic ^{48}Ni. Physicists set a primary beam of ^{58}Ni with the energy of 95MeV per nucleon to hit a natural Nickel target in the superconducting solenoids [2]. The intensity of primary beam does not reach the requirement before it was achieved through and intense ion-source development program, which is a technique can make the Nickel act like the gas in the ion source. Then the transmission of the GANIL cyclotrons can accelerate the primary beam to the high intensity. This experiment produced four "events" of the doubly magic ^{48}Ni nucleus. Meanwhile, the experiment produced other exotic proton-rich nuclei as well. There are about 100 events of ^{49}Ni, 50 events of ^{45}Fe and 290 events of ^{42}CI [2]. It is obvious that doubly magic ^{48}Ni nucleus occupied a small percentage, and it is hard to create. The results of GANIL experiment is alike another experiment which is processed in GSI laboratory about three years ago. In the GSI laboratory, 5 events of ^{49}Ni, 3 events of ^{45}Fe and 12 events of ^{42}CI were determined. The ratio of these new isotopes is like the experiment in GANIL. By the recent observations, physicists observed that the doubly magic ^{48}Ni nucleus has the half-life about 0.5 microsecond. The doubly magic ^{48}Ni nucleus has the relatively long half-life than the flight time of the projectile fragments between the production target and the detection area [2]. (Figure 2) Therefore, doubly magic ^{48}Ni nucleus is stable.



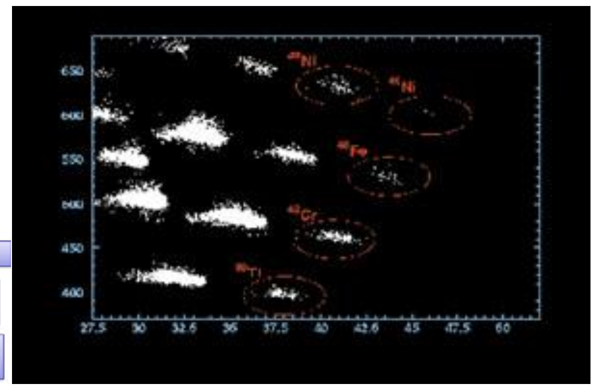


Figure 1: Schematic GANIL Layout **Figure 2: Energy loss/time of flight**

Effort to investigation the doubly magic ^{78}Ni

Differ from the ^{48}Ni, there is another Nickel isotope defined by doubly magic as well, which is ^{78}Ni. ^{78}Ni, has 28 protons and 50 neutrons, both are magic number. Therefore, ^{78}Ni is the doubly magic nucleus. Physicist did lots of work to investigate and try to create the doubly magic ^{78}Ni nucleus. However, the ^{79}Ni is extremely difficult to create in laboratory. There were two group of researchers did great improvement for searching the ^{78}Ni nucleus [1]. Both of two groups created and studied the ^{79}Cu nucleus, which is only one proton away from the doubly magic ^{78}Ni nucleus. The two teams used different approaches to try to find the existence of ^{78}Ni nucleus. The first team of researchers, which is led by Louis Oliver at the Radioactive Ion Beam Factory (RIBF) facility in Tokyo, Japan [5]. (Figure 3) They used the knockout reaction to investigate the nucleus close to doubly magic ^{78}Ni nucleus. The knock out reaction can eject a proton from a ^{80}Zn projectile. This process can produce a ^{79}Cu nucleus. Then the team manifested that ^{79}Cu can be characterized as the doubly magic ^{78}Ni nucleus with one extra proton by the shell model calculations [3]. The Oliver team completed the spectroscopic measurements of ^{79}Cu nucleus in an excited energy state. This result showed that the ^{79}Cu nucleus is the great description for doubly magic ^{78}Ni nucleus, which has one more proton in the next shell above the closed and completed 28 proton shell. Furthermore, another team of researchers, which is led by Welker at CERN's Isotope Separator On Line Device (ISOLDE) facility. This team measured the mass of the copper isotopes in the chain from ^{75}Cu to ^{79}Cu by the advanced technology at CERN. They performed the most precise measurements of the masses of those copper isotopes, which are just one proton away from the Nickel nucleus. According to the equation: E=mc^2. The nucleus mass can be seen the direct measurement of the ground state energy of the nucleus [4]. Then the team used the ISOLTRAP, which is an experiment in the facility. This experiment could use the ion traps to weigh each nucleus to obtain their binding energy. Then they can utilize their observations and experimental results to show the ^{79}Cu could be characterized as an individual proton which is fitting in the doubly magic ^{78}Ni nucleus. Moreover, there is another experiment processed in ISOLDE, which is called CRIS. This experiment uses a different technique. The precision method of laser spectroscopy, it can measure the different property of the same isotopic chain. Then, they can use the same theoretical model calculations which is consistent. This is great evidence that manifest the nature of doubly magic ^{78}Ni nucleus [4]. These two teams of physicists obtained the compatible result by two different approaches. The experimental result is that the ^{79}Cu is the best version to describe the doubly magic ^{78}Ni nucleus, which is just one proton away from it [5].

Figure 3 Magic factory: the RIBF in Japan

Conclusion

The electrons around the nucleus can fill different shell. Once the number of electron can fill the shell exactly, the binding energy of the electron is at maximum. And the electrons can become more stable. For instance, the electrons of noble gas atoms can fill their corresponding electron shell. Then the noble gas atoms are stable. Similarly, to the electrons shells, the protons and neutrons in nucleus can also fill up the shells gradually. The nucleus can become more stable if the shells of nucleons are full [4]. The number which can fill up the shell for nucleons in nucleus call magic number. When the number of proton or neutron reach the magic number, the nucleus would gain more stability. Intuitively, the doubly magic nucleus would be more stable as well. The ^{48}Ni and ^{78}Ni are the doubly magic nucleus which physicists try to investigate. The doubly magic ^{48}Ni nucleus had been detected, and physicists confirmed that the doubly magic ^{48}Ni nucleus is more stable by experimental results. For the doubly magic ^{78}Ni nucleus, even though physicists did not detect or reproduce it directly until now. They confirmed that ^{78}Ni is the doubly magic nucleus, and physicists could reproduce ^{79}Cu nucleus, which is just one proton away from the doubly magic ^{78}Ni nucleus. In addition, the shell-model calculations show that the ^{79}Cu has similar structure to the doubly magic ^{78}Ni nucleus.

Reference

[1] Bazin, Daniel. “Viewpoint: Doubly Magic Nickel.” *Physics*, American Physical Society, 6 Nov. 2017, physics.aps.org/articles/v10/121.

[2] CERN COURIER. “Discovery of Doubly Magic Nickel.” *CERN Courier*, 15 May 2000, cerncourier.com/cws/article/cern/28206.

[3] Yirka, Bob. “Nickel-78 Confirmed to Be Doubly Magic.” *Phys.org - News and Articles on Science and Technology*, 8 Nov. 2017, phys.org/news/2017-11-nickel-doubly-magic.html.

[4] Jarlett, Harriet. “CERN Accelerating Science.” *Doubly Magic Nickel from One Proton Away | CERN*, 24 Nov. 2017, home.cern/scientists/updates/2017/11/doubly-magic-nickel-one-proton-away.

[5] Johnston, Hamish. “Neutron-Rich Nickel-78 Is Doubly Magic – Physics World.” *Physics World*, 7 Dec. 2017, physicsworld.com/a/neutron-rich-nickel-78-is-doubly-magic/.